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MINIMUM NONPROPAGATION DISTANCE FOR 155 MM M483 HE PROJECTILES

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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DOVER, NEW JERSEY

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The Energetic Systems Process Division, LCWSL, is engaged in the development of safety criteria in support of LAP (Load-Assembly-Pack) facilities as part of the overall modernization and expansion of LAP manufacturing explosive facilities. One of these criteria is the safe separation distance between 155 mm M483 HE projectiles as they are transported along the production line.

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Testing of this projectile to determine the minimum nonpropagation distance between donor and acceptor units was started at Yuma Proving Ground, with follow-up tests carried out at the National Space Technology Laboratories and Hawthorne Army Ammunition Plant. The test program was divided into three phases with a total of 100 tests. Phase 1 consisted of a series of exploratory tests to determine the safe separation distance between projectiles contained in a simulated transfer pallet. In Phase 2 an empty projectile was used as a shield halfway between the donor unit and each acceptor unit. Phase 3 consisted of a series of tests to determine the safe separation distance between projectiles that would not provide nonpropagation of a detonation and would not allow adjacent projectiles to contaminate the immediate area with scattered and armed grenades.

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INTRODUCTION

Background

At the present time, an Army-wide modernization and expansion program is currently underway for the purpose of upgrading existing and developing new LAP (Load-Assembly-Pack) manufacturing explosive facilities. This effort will enable said facilities to achieve increased production cost effectiveness with improved safety, as well as provide manufacturing facilities for new improved weaponry within existing LAP manufacturing facility configurations. As part of the overall modernization and expansion program, the Special Technology Branch, Energetic Systems Process Division, LCWSL of ARRADCOM, Dover, New Jersey, under the direction of the U.S. Army Production Base Modernization Agency, is presently engaged in the development of energetic system safety criteria in support of ammunition plant LAP operations.

An essential component of this program is the development of minimum safe separation (non-propagative) distance criteria between 155mm M483 HE projectiles as they are transported along the production line (fig. 1).

Objective

The primary objective of this program segment is twofold:

1. To establish and statistically confirm the safe non-propagation separation distance between single 155mm M483 HE projectiles as they progress along a loading line and

2. To develop safety criteria for use in existing plants (Kansas and Lone Star AAPs) as well as for planning purposes for proposed future plants (Milan and Mississippi AAPs).

The overall program objective is to supplement and/or modify existing safety regulations and criteria pertaining to the safe spacing of ammunition and other energetic materials in order to assist explosive loading plants in their LAP facility layouts for the most effective and economic man-machine relationship.

Criteria

This test program was implemented to determine the safe spacing of 155mm M483 HE projectiles under simulated loading plant conditions and/or the necessary shielding between projectiles, such that the effects of a major accidental detonation of a munition on the assembly line will be limited to the immediate area or loading bay, and not propagated to adjacent loading activities. Therefore, the only acceptable criteria to establish the safe separation distances is the non-propagation of the donor detonation to the acceptor units. Since this projectile contains a quantity of fuzed sub-projectiles (grenades), the safe spacing criteria contains an additional requirement of non-arming of acceptor projectile grenades.

Note that all separation distances cited in this report were measured between axial centerlines of the donor and acceptor units.

TEST CONFIGURATION

General

Testing of the 155mm M483 HE projectile to determine the minimum non-propagation distance between donor and acceptor units was begun at Yuma Proving Ground, Arizona, with follow-up tests conducted at the National Space Technology Laboratories, Mississippi, and Hawthorne Army Ammunition Plant, Nevada.

After a facility survey of 155mm M483 HE projectile LAP operations at Lone Star AAP, Texas, it was determined that the project test conditions should be a vertical base-up position. In order to fully simulate the LAP line conditions, the nose-located expelling charge was removed, as was the base plug and related padding, to expose the top row of sub-projectiles (M42/M46 grenades). Initial testing was conducted with each projectile contained within a pallet cone that simulated the actual production line cross-transfer pallets in configuration, wall thickness, and materials. Final testing was within a shielded transfer pallet that is considered to be a prototype for adaptation to the various production facilities.

The testing program, originally intended for one exploratory test phase, necessitated the implementation of a second exploratory test phase, since the non-propagative distance was becoming in excess of the 1.5-meter (5.0-foot) guideline distance compatible with the equipment spacing at the existing loading plants. Finally, a third exploratory phase tested out a prototype shielding method for the transfer pallet, and that design was subjected to confirmatory tests.

Test Specimen

Each test specimen consisted of a single 155mm M483 HE projectile contained in a vertical base-up position within either an unshielded or shielded simulated cross-transfer system pallet. The projectile (fig. 2) contained 11 rows, each with 8 grenades, for a total of 88 dual purpose grenades (64 each M42 followed by 24 each M46). The last three rows were M46 grenades since they have stronger bodies to withstand the weapon setback forces experienced when the projectile is fired from a 155mm howitzer. The M42 and M46 grenades are ground-burst submissiles which air arm and function upon impact, providing anti-armor (shaped charge) and anti-personnel (fragmented body) capabilities. The completely assembled projectile weighed 47 kilograms (102.6 pounds) and contained 2.8 kilograms (6.25 pounds) of Composition

A5 within the grenade load, plus 51 grams (1.8 ounces) of M10 propellant in the expulsion charge. As mentioned earlier, each projectile had its **expulsion** charge and base plug removed prior to test functioning.

Test Arrangements

Test Phase 1

The first test phase was a series of exploratory tests to determine a safe separation distance between projectiles contained in a simulated transfer pallet (figs. 3 and 4). Each test consisted of three test specimens arranged in a straight line configuration (fig. 5) with the central specimen serving as the donor projectile, while the two last specimens were the acceptor projectiles. This test arrangement produced two acceptor data points for each donor detonation initiated.

Test Phase 2

A second test phase was initiated using a configuration similar to that of Test Phase 1, except that an empty projectile body, also within a simulated transfer pallet, was positioned at the half distance between the donor and acceptor units, to act as a shield (fig. 6). This test phase was undertaken in order to check out an interim shielding method for AAP use, until a finalized design can be approved for plant installation.

Test Phase 3

A third test phase, utilizing a prototype shielded pallet (fig. 7), was initiated in an attempt to establish a safe non-propagative distance that would be compatible with machinery spacing in existing loading plants. This prototype transfer pallet had 2.5-centimeter (1.0-inch) thick shields on both ends of each transfer pallet and was contained on an elevated rail system in order to simulate the conveyor's standoff from the building floor (figs. 8 and 9). Since this third test phase was the only one to establish a safe non-propagative distance that was compatible with existing production lines, it is the only phase to contain both exploratory and confirmatory tests.

Method of Initiation

Initially, there were some questions as to the ability of an electrically-initiated blasting cap being able to initiate the donor projectile to a fully high order detonation; therefore, a 115-gram (0.25-lb) charge of C4 explosive with an M6 blasting cap (fig. 10) was placed over the center grenade in the last row of the base-up donor projectile. During an interim review of Phase 1 test data, the potential of the extra energy derived from the C4 explosive effecting the detonation propagation was questioned and in subsequent tests, only the M6 blasting cap was utilized (fig. 11) with no noticeable change in the resulting data. The first 35 tests of Phase 1 were conducted utilizing the C4 explosive; all other tests - the remainder of Phase 1, all of Phase 2, and both exploratory and confirmatory tests of Phase 3, utilized only the M6 blasting cap as the source of donor initiation.

TEST RESULTS

General

As previously mentioned, two methods of donor initiation were utilized resulting in no noticeable variations in the acceptor data. Also, by placing a witness plate under the donor projectile on selected test samples, it was determined by the placement of the shaped charge jet holes, that all grenades within the projectile detonated high order (fig. 12).

The actual tests to determine the safe non-propagation distance for single 155mm M483 HE projectiles were grouped into three distinctive test phases - unshielded projectiles, empty projectiles as shields between live load projectiles, and prototype shielded pallets, with the results as described below.

Single Projectiles Without Shielding (Test Phase 1)

The unshielded test configuration consisted of a donor projectile and two acceptor projectiles arranged in a straight line, and contained within simulated transfer pallets without any form of shielding between them, as shown in Figure 5. The separation distances employed during Test Phase 1 ranged from 0.91 to 3.10 meters (3.0 to 10.0 feet) with propagation-to-detonation reactions occurring at most distances tested. Table 2 is an annotated tabulation of all the unshielded tests conducted. From the data from Test Nos. 1 through 35 inclusive, it was concluded that the safe non-propagation distance would be considerably greater than the 1.5-meter (5.0 feet) guideline distance for compatibility with the equipment spacing in existing loading plants. Therefore, the remainder of the tests presented in Table 1 (Tests No. 36 through 48) were an attempt to determine the detonation propagation probability response distribution. However, the statistically determined value was again greater than the guideline distance and testing of the unshielded configuration was discontinued.

Figures 13, 14, and 15 present general and close-up views of post-test conditions of the unshielded projectile configuration. Figure 13 is the general view showing the donor blast location and the two overturned acceptor projectiles separated from their pallets. Figure 14 is a close-up view of an overturned projectile with a number of spilled grenades. Note the ruptured grenade (probably a low order detonation) in the right foreground. Finally, Figure 15 shows a standing pallet out of which the projectile was torn by the blast.

Empty Projectiles as Shields (Test Phase 2)

The second test configuration, utilizing an empty projectile as a shield positioned half-way between the donor unit and each acceptor unit arranged in a straight line (fig. 6), was tested in order to establish a safe non-propagation separation distance within the 1.5-meter (5-foot) guideline distance. A total of 28 tests were conducted, utilizing empty projectiles as shields, as shown in Table 2. After initially testing at 2.2 meters (7.0 feet), a series of 26 tests were conducted at a distance of 0.9 meter (3.0 feet) without an actual propagation of a donor detonation to the acceptor projectile. However, in one case, the acceptor projectile (No. 16L of Table 2) traveled 31.5 meters (102.0 feet), spilling approximately half of its grenade load; then, the remainder within the shell body functioned to a high order detonation, apparently on ground impact. While the shield (empty projectile) did absorb all the donor fragments directed at the acceptor projectiles (fig. 16), the donor blast caused the shielding projectile to impact on the acceptors with such force that, in a few cases, it caused the deformation of the acceptor projectile to the point that the sub-projectiles were crimped in place (fig. 17). Test Acceptor Nos. 6L, 6R, 21L, 23L and 24R were affected in this manner.

Another potential source of safety hazards was noted during testing of the second configuration; namely, the apparently random distribution of live and potentially armed HE grenades throughout the test area. From the 26 tests conducted at the 0.90-meter (5-foot) separation distance, a total of 1,991 grenades were spilled from their projectile bodies. Of that number, 231 grenades were found in an armed condition with an additional 25 having functioned on impact. Thus, the acceptor projectiles were ejecting approximately half their grenade load into the immediate area and, on the average, one grenade per test was arming and impacting with enough force to function high order.

Prototype Transfer Pallet (Test Phase 3)

The third test configuration (fig. 7), utilizing a prototype transfer pallet with 2.5-centimeter (1.0-inch) thick shields at each end, was tested to determine a safe spacing between projectiles that would not only provide non-propagation of a detonation, but would also not allow adjacent projectiles to contaminate the immediate area with scattered and armed grenades. A total of eight tests (16 data points) were conducted utilizing the prototype pallet in which the acceptor projectiles were inert shell bodies (Table 3). This was the exploratory test series, and the utilization of inert acceptors not only allowed for their reuse, but also permitted the conduction of tests at sites from which they would normally have been banned. Five of the exploratory tests were conducted with the pallets either abutting each other (fig. 9) or spaced 72 centimers (28 inches), center-to-center. There was no indication of a potential propagation and/or grenade spillage. An attempt to conduct additional tests, reusing existing acceptor pallets from previous tests (Tests Nos. E6, E7, and E8, Table 3) at the zero pallet spacing, resulted in excessive pallet failures and was discontinued.

The third configuration confirmation test series consisted of 16 firings (32 data points) utilizing the prototype pallets and live acceptors. Tests Nos. 9 through 24 inclusive (Table 3) are a detailed record of the tests. In Test No. C14, one of the acceptor projectiles became loose within its pallet, resulting in a minor grenade spill (fig. 18). All the spilled grenades fell within a 90-centimeter (3.0-foot) radius of the acceptor projectile. Also, none of the grenades were armed or had their deployment ribbons unfurled (fig. 19).

Analyses of Test Results

The first test phase, with unshielded projectiles in simulated pallets, consisted of 70 data points with C4 explosive initiation and 26 data points with M6 blasting cap initiation. However, a resultant analysis indicated an insignificant acceptor damage variation between the two initiation methods and, as a result, the data was combined to yield 96 significant data points. Since a functional safe non-propogation separation distance compatible with the loading plant guidelines (1.5 meters/5.0 feet) could not be experimentally established prior to the discontinuance of Phase 1, an attempt was made to determine the theoretical distance through statistical analysis. A Weibull distribution methodology was utilized, which exhibits many robust properties which are desirable for such a process in which the true distribution is unknown. It is as follows:

$$F(x) = 1 - \exp -[(x - y)/\theta]^{\alpha}, \text{ for } x > y$$

where x = separation distance (ft)

θ = scale parameter

α = shape parameter

y = location parameter

Most parameters were estimated using the method of maximum likelihood and a computer program for performing the calculations was initiated. Based upon the combined data points of Phase 1, mean distances for different probabilities of propagation were calculated as shown in Table 4. From this table, it is evident that the Phase 1 configuration will not yield an acceptable safe separation distance within loading plant guidelines.

The second test phase, utilizing empty projectile bodies as shields between live projectiles, was implemented with a total of 26 tests (52 data points) at the 0.9-meter (3.0-foot) separation distance. This resulted in only one case of an acceptor projectile detonation (Test No. 16L of Table 2) and it is believed that this detonation was initiated by the impacting of an armed grenade within the projectile body, rather than by the donor detonation. However, another hazard observed in the second phase was the spilling of approximately half of the grenade loads from within the acceptor projectiles and an average of one grenade for every two acceptors arming and impacting with enough force to function with a high order detonation.

The third test phase, utilizing the prototype pallet, was implemented with a total of 14 tests (28 data points) at zero pallet spacing, or a 72-centimeter (28-inch) center-to-center spacing. In none of these tests was there any propagation of the donor detonation, and only in three cases was minor grenade spillage evident. Also, all of the grenades that were spilled were not armed and did not even have their arming ribbons unfurled; therefore, utilizing the prototype pallet, a safe distance was established.

Variations in manufacturing tolerances, materials, wear, etc., required that statistical reasoning be enlisted in the interpretation of the established non-propagation distance test data. The actual probability of the propagation of an explosive incident is dependent upon the confidence level desired, and has lower and upper limits. The lower limit for all confidence levels is zero; whereas the upper or practical limit is a function of the number of observations or test data points available for analysis (see Appendix for statistical theory). In Phase 2 testing, the upper limit of the probability of propagation is 9.1% at the 95% confidence level; however, it is only for the propagation of an explosive incident from one projectile to the next, and does not take into consideration the potential propagation probability from a projectile to exposed trays of grenades (64 per tray) that are located within the various projectile loading stations (fig. 1). Utilizing the data points generated from the prototype pallet tests, the upper limit of the probability of propogation is 10.9% at the 95% confidence level, without any potential of an armed and thrown grenade causing a secondary explosive incident. This is equivalent to stating that in a large number of tests, 95 out of 100 times, the probability of an explosive event will be less than, or equal to, the 10.9% value. This is an indication of the quality of the tests and the reliability that can be placed upon the conclusion drawn from the testing (fig. 20).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Single Projectile Without Shield

It may be concluded from the Phase I configuration tests, that the original LAP operational layout for the 155mm M483 HE projectiles could lead to devastating effects if an explosive incident should occur during active line operations at the loading plants. From the tests conducted, it was observed that propagation to detonation reactions in acceptor projectiles occurred at distances far in excess of the 1.5-meter (5.0-foot) guideline distance required for equipment spacing at the loading plants.

Single Projectile With Empty Projectile Shields

It may be concluded from the Phase 2 configuration tests that, if a separation distance of 0.9 meter (3.0 feet) is maintained between live projectiles using empty projectile bodies as shields between the live ones, the probability of a detonation of adjacent projectiles will be reduced to an acceptable level (9.1% at the 95% confidence level). However, with the presence of exposed trays of grenades (64 per tray) located immediately adjacent to the various projectile loading stations, the probability of an explosive incident propagating from a detonated grenade spilled by a displaced projectile to a tray of grenades, may increase to an unacceptable probability of detonation at the 95% confidence level.

Single Projectile Within Prototype Pallet

It may be concluded from the results of the prototype pallet tests, that pallets with 2.5-centimeter (1.0-inch) thick shields can be positioned with 72-centimeter (28-inch) center-to-center spacing between projectiles (zero pallet spacing) without a significant chance of propagation of an explosive incident. Also, the rigidity of the prototype pallet is sufficient to prevent major grenade spills and the resultant hazard of secondary sub-projectile detonations.

Recommendations

Based upon the results of the 155mm M483 HE projectile safe non-propagation separation distance tests, it is recommended that the Phase 3 pallet design (with end shields) be considered as a prototype; and those loading facilities, either in operation or being planned, consider adapting the prototype to their line layouts.

Table 1. 155mm M483 HE projectiles without shield - Test results (Phase 1)

Test No.	Acceptor	Separation distance m	Separation distance (ft)	Detonation (a)	Acceptor distance thrown m	Acceptor distance thrown (ft)	Grenades Spilled	Grenades Armed	Grenades Detonation (b)
1	L	1.5	(5.0)	0	5.8	(19.0)	38	-	-
	R	1.5	(5.0)	0	3.9	(13.0)	2	-	-
2	L	1.2	(4.0)	0	3.9	(13.0)	25	-	-
	R	1.2	(4.0)	0	5.6	(18.0)	3	-	-
3	L	0.9	(3.0)	0	4.0	(13.1)	40	-	-
	R	0.9	(3.0)	LOD	NA		21	-	-
4	L	1.2	(4.0)	0	3.1	(10.0)	22	-	-
	R	1.2	(4.0)	0	3.7	(12.0)	12	-	-
5	L	1.2	(4.0)	HOD	NA		-	-	-
	R	1.2	(4.0)	0	4.5	(14.5)	-	-	-
6	L	1.4	(4.5)	0	3.3	(10.7)	2	-	-
	R	1.4	(4.5)	0	6.2	(20.0)	3	-	-
7	L	1.4	(4.5)	0	2.8	(9.2)	2	-	-
	R	1.4	(4.5)	0	3.3	(10.7)	12	-	-
8	L	1.4	(4.5)	0	5.6	(18.0)	31	-	-
	R	1.4	(4.5)	0	5.4	(17.5)	11	-	-
9	L	1.4	(4.5)	0	8.1	(26.0)	28	-	-
	R	1.4	(4.5)	0	1.9	(6.0)	0	-	-

Table 1. 155mm M483 HE projectiles without shield - Test results (Phase 1) (continued)

Test No.	Acceptor	Separation distance m	Separation distance (ft)	Detonation (a)	Acceptor distance thrown m	Acceptor distance thrown (ft)	Grenades: Spilled	Grenades: Armed	Grenades: Detonation (b)
10	L	1.4	(4.5)	0	4.8	(15.7)	0	-	-
	R	1.4	(4.5)	HOD	NA		-	-	-
11	L	1.5	(5.0)	0	5.7	(18.1)	26	-	-
	R	1.5	(5.0)	0	6.1	(19.1)	11	-	-
12	L	1.5	(5.0)	0	-		2	-	-
	R	1.5	(5.0)	0	-		25	-	-
13	L	1.5	(5.0)	0	2.3	(7.7)	22	-	-
	R	1.5	(5.0)	0	4.0	(13.1)	15	-	-
14	L	1.5	(5.0)	0	3.5	(11.6)	16	-	-
	R	1.5	(5.0)	0	3.4	(11.0)	4	-	-
15	L	1.5	(5.0)	0	2.9	(9.3)	4	-	-
	R	1.5	(5.0)	0	6.4	(20.8)	10	-	-
16	L	1.5	(5.0)	0	3.5	(11.6)	2	-	-
	R	1.5	(5.0)	HOD	NA		-	-	-
17	L	1.5	(5.0)	0	3.1	(10.0)	2	-	-
	R	1.5	(5.0)	0	3.5	(11.6)	3	-	-
18	L	1.7	(5.5)	0	3.9	(13.0)	4	0	0
	R	1.7	(5.5)	0	9.6	(31.2)	10	0	0

Table 1. 155mm M483 HE projectiles without shield - Test results (Phase 1) (continued)

Test No.	Acceptor	Separation distance m	(ft)	Detonation (a)	Acceptor distance thrown m	(ft)	Grenades Spilled	Grenades Armed	Grenades Detonation (b)
19	L	1.7	(5.5)	0	-		14	-	-
	R	1.7	(5.5)	0	-		16	-	-
20	L	1.7	(5.5)	0	2.2	(7.0)	0	-	-
	R	1.7	(5.5)	0	6.5	(21.0)	40	-	-
21	L	1.7	(5.5)	0	3.3	(10.7)	26	-	-
	R	1.7	(5.5)	0	2.7	(9.0)	4	-	-
22	L	1.7	(5.5)	0	2.6	(8.5)	1	-	-
	R	1.7	(5.5)	0	2.7	(9.0)	0	-	-
23	L	1.7	(5.5)	0	3.9	(13.0)	5	-	-
	R	1.7	(5.5)	0	2.4	(7.8)	2	-	-
24	L	1.7	(5.5)	0	-		2	-	-
	R	1.7	(5.5)	0	-		0	-	-
25	L	1.7	(5.5)	0	-		4	-	-
	R	1.7	(5.5)	0	-		1	-	-
26	L	1.7	(5.5)	0	-		24	-	-
	R	1.7	(5.5)	0	-		21	-	-
27	L	1.7	(5.5)	0	-		2	-	-
	R	1.7	(5.5)	0	-		1	-	-

Table 1. 155mm M483 HE projectiles without shield - Test results (Phase 1) (continued)

Test No.	Acceptor	Separation distance m	Separation distance (ft)	Detonation (a)	Acceptor distance thrown m	Acceptor distance thrown (ft)	Grenades: Spilled	Grenades: Armed	Grenades: Detonation (b)
28	L	1.7	(5.5)	0	-		5	-	-
	R	1.7	(5.5)	0	-		2	-	-
29	L	1.7	(5.5)	0	2.4	(7.8)	1	-	-
	R	1.7	(5.5)	0	2.4	(7.8)	1	-	-
30	L	1.7	(5.5)	0	-		10	-	-
	R	1.7	(5.5)	0	-		46	-	-
31	L	1.7	(5.5)	0	19.0	(61.0)	6	-	-
	R	1.7	(5.5)	HOD	NA		-	-	-
32	L	1.9	(6.0)	0	-		0	-	-
	R	1.9	(6.0)	0	-		6	-	-
33	L	1.9	(6.0)	0	-		1	-	-
	R	1.9	(6.0)	0	-		3	-	-
34	L	1.9	(6.0)	0	-		2	-	-
	R	1.9	(6.0)	0	-		0	-	-
35	L	1.9	(6.0)	HOD	NA		-	-	-
	R	1.9	(6.0)	0	-		2	-	-
36	L	2.2	(7.0)	0	6.5	(21.0)	40	-	-
	R	2.2	(7.0)	0	3.1	(10.0)	0	-	-

Table 1. 155mm M483 HE projectiles without shield - Test results (Phase 1) (continued)

Test No.	Acceptor	Separation distance m	(ft)	Detonation (a)	Acceptor distance thrown m	(ft)	Grenades: Spilled	Grenades: Armed	Grenades: Detonation (b)
37	L	1.2	(4.0)	0	6.2	(20.0)	10	-	-
	R	1.2	(4.0)	0	2.2	(7.0)	4	-	-
38	L	0.8	(2.5)	0	10.8	(35.0)	2	-	-
	R	0.8	(2.5)	0	18.5	(60.0)	9	-	-
39	L	0.5	(1.5)	0	-		17	2	0
	R	0.5	(1.5)	0	-		16	3	0
40	L	0.5	(1.5)	0	-		25	2	0
	R	0.5	(1.5)	HOD	NA		-	-	-
41	L	2.2	(7.0)	0	-		1	0	0
	R	2.2	(7.0)	LOD	NA		18	1	0
42	L	3.1	(10.0)	0	4.0	(13.1)	10	0	0
	R	3.1	(10.0)	0	4.6	(15.0)	3	0	0
43	L	2.6	(8.5)	0	-		1	0	0
	R	2.6	(8.5)	0	0		0	0	0
44	L	2.4	(7.8)	0	-		3	0	0
	R	2.4	(7.8)	0	-		0	0	0
45	L	1.3	(4.3)	0	-		5	0	0
	R	1.3	(4.3)	0	-		4	0	0

Table 1. 155mm M483 HE projectiles without shield - Test results (Phase 1) (concluded)

Test No.	Acceptor	Separation distance m	Separation distance (ft)	Detonation (a)	Acceptor distance thrown m	Acceptor distance thrown (ft)	Grenades Spilled	Grenades Armed	Grenades Detonation (b)
46	L	0.8	(2.5)	0	-		18	0	0
	R	0.8	(2.5)	0	-		25	0	0
47	L	0.6	(1.9)	HOD	NA		-	-	-
	R	0.6	(1.9)	0	-		-	-	-
48	L	0.7	(2.3)	0	-		-	-	-
	R	0.7	(2.3)	HOD	NA		-	-	-

(a) 0 - No detonation propagation
LOD - Low order detonation (some grenades recovered).
HOD - High order detonation (no grenades recovered and shell body destroyed).

(b) Determined by audio count immediately after donor detonation. Could not differentiate between left and right acceptors.

Table 2. 155mm M483 HE projectiles with empty projectile shield - Test results (Phase 2)

Test No.	Acceptor	Separation distance m	Separation distance (ft)	Detonation (a)	Acceptor distance thrown m	Acceptor distance thrown (ft)	Shield distance thrown m	Shield distance thrown (ft)	Grenades Spilled	Grenades Armed	Grenades Detonation (b)
1	L	2.2	(7)	0	2.2	(7)	3.9	(13.)	1	0	0
	R	2.2	(7)	0	4.3	(14)	10.5	(34)	15	0	-
2	L	1.2	(4)	0	14.0	(45)	23.0	(75)	0(c)	0	1
	R	1.2	(4)	0	18.5	(60)	22.0	(70)	33	1	-
3	L	0.9	(3)	0	35.0	(115)	12.5	(40)	47	5	0
	R	0.9	(3)	0	27.5	(89)	19.5	(63)	30	1	-
4	L	0.9	(3)	0	24.7	(80)	12.5	(40)	58	3	0
	R	0.9	(3)	0	27.5	(89)	33.0	(108)	39	1	-
5	L	0.9	(3)	0	26.0	(84)	7.7	(25)	47	8	1
	R	0.9	(3)	0	33.0	(108)	20.5	(66)	49	1	0
6	L	0.9	(3)	0	14.0	(45)	27.0	(88)	0(c)	0	0
	R	0.9	(3)	0	27.5	(89)	-		0(c)	0	0
7	L	0.9	(3)	0	26.0	(84)	29.5	(96)	57	4	0
	R	0.9	(3)	0	16.8	(54)	18.5	(60)	6	0	1
8	L	0.9	(3)	0	26.5	(86)	17.5	(56)	9	2	0
	R	0.9	(3)	0	18.5	(60)	28.0	(90)	49	1	-
9	L	0.9	(3)	0	31.0	(100)	22.0	(70)	27	1	0
	R	0.9	(3)	0	18.5	(60)	26.5	(86)	59	8	-
10	L	0.9	(3)	0	21.5	(69)	15.8	(51)	26	4	0
	R	0.9	(3)	0	35.0	(115)	20.5	(66)	2	0	1

Table 2. 155mm M483 HE projectiles with empty projectile shield - Test results (Phase 2) (continued)

Test No.	Acceptor	Separation distance m	(ft)	Detonation (a)	Acceptor distance thrown m	(ft)	Shield distance thrown m	(ft)	Grenades Spilled	Armed	Detonation (b)
11	L	0.9	(3)	0	28.0	(90)	31.5	(102)	46	0	1
	R	0.9	(3)	0	35.7	(117)	19.5	(63)	71	4	-
12	L	0.9	(3)	0	32.5	(105)	37.0	(120)	47	10	2
	R	0.9	(3)	0	42.0	(138)	11.0	(36)	39	0	-
13	L	0.9	(3)	0	25.5	(83)	20.5	(66)	55	4	2
	R	0.9	(3)	0	20.5	(66)	24.5	(78)	53	1	-
14	L	0.9	(3)	0	38.5	(123)	14.8	(48)	42	3	5
	R	0.9	(3)	0	20.5	(66)	28.5	(93)	26	2	-
15	L	0.9	(3)	0	33.0	(108)	39.0	(127)	42	6	0
	R	0.9	(3)	0	29.5	(96)	29.5	(96)	54	7	-
16	L	0.9	(3)	HOD(d)	31.5	(102)	26.0	(84)	39	4	3
	R	0.9	(3)	0	32.5	(105)	20.5	(66)	0	0	1
17	L	0.9	(3)	0	27.0	(88)	26.0	(84)	46	7	3
	R	0.9	(3)	0	44.0	(142)	8.4	(27)	48	9	-
18	L	0.9	(3)	0	-		-		42	2	1
	R	0.9	(3)	0	-		-		15	1	1
19	L	0.9	(3)	0	37.0	(120)	27.5	(89)	49	5	3
	R	0.9	(3)	0	33.0	(108)	18.5	(60)	42	10	-

Table 2. 155mm M483 HE projectiles with empty projectile shield - Test results (Phase 2) (concluded)

Test No.	Acceptor	Separation distance m	(ft)	Detonation (a)	Acceptor distance thrown m	(ft)	Shield distance thrown m	(ft)	Grenades Spilled	Grenades Armed	Grenades Detonation (b)
20	L	0.9	(3)	0	41.0	(132)	14.0	(45)	48	4	1
	R	0.9	(3)	0	37.0	(120)	22.5	(72)	48	5	-
21	L	0.9	(3)	0	31.5	(102)	27.5	(89)	0(b)	0	1
	R	0.9	(3)	0	32.5	(105)	42.0	(138)	87	17	-
22	L	0.9	(3)	0	47.0	(150)	9.4	(30)	47	18	0
	R	0.9	(3)	0	-		-		48	7	-
23	L	0.9	(3)	0	47.0	(150)	32.5	(105)	0(c)	0	2
	R	0.9	(3)	0	27.5	(89)	12.2	(39)	47	9	-
24	L	0.9	(3)	0	-		-		83	15	1
	R	0.9	(3)	0	-		-		0(c)	0	-
25	L	0.9	(3)	0	38.5	(126)	34.5	(111)	45	6	0
	R	0.9	(3)	0	24.5	(78)	8.4	(27)	24	5	-
26	L	0.9	(3)	0	-		-		3	0	0
	R	0.9	(3)	0	-		-		49	11	-
27	L	0.9	(3)	0	34.5	(111)	-		44	6	0
	R	0.9	(3)	0	32.5	(105)	-		53	6	-
28	L	0.9	(3)	0	18.5	(60)	28.0	(90)	52	0	0
	R	0.9	(3)	0	58.0	(189)	39.0	(127)	52	8	-

(a) 0 - No detonation propagation
LOD - Low order detonation (some grenades recovered)
HOD - High order detonation (no grenades recovered and shell body destroyed).

(b) Determined by audio count immediately after donor detonation. Could not differentiate between left and right acceptors.

(c) Shield hitting acceptor crimped grenades in projectile.

(d) Detonation occurred after impact of acceptor at 102 feet from pre-test location; cause unknown.

Table 3. 155mm M483 HE projectiles within prototype pallet
Test Results (Phase 3)

Test No.	Acceptor	Separation distance m	(ft)	Detonation*	Grenades Spilled	Grenades Armed	Grenades Detonation
E1	L	0		NO	Pallet reusable.		
	R	0		NO	Pallet reusable.		
E2	L	0		NO	Pallet damaged.		
	R	0		NO	Pallet damaged.		
E3	L	0		NO	Pallet reusable.		
	R	0		NO	Pallet damaged.		
E4	L	0		NO	Pallet damaged.		
	R	0		NO	Pallet damaged.		
E5	L	0.3	(1.0)	NO	Pallet damaged.		
	R	0.3	(1.0)	NO	Pallet damaged.		
E6	L	0		NO	Reused pallet destroyed.		
	R	0		NO	Reused pallet destroyed.		
E7	L	0		NO	Reused pallet destroyed.		
	R	0		NO	Reused pallet destroyed.		
E8	L	0		NO	Reused pallet destroyed.		
	R	0		NO	Reused pallet destroyed.		
C9	L	0		NO	0	0	0
	R	0		NO	0	0	0

*Estimated on Tests Nos. 1 through 8 inclusive since inert acceptors were used.

Table 3. 155mm M483 HE projectiles within prototype pallet
Test Results (Phase 3)
(continued)

Test No.	Acceptor	Separation distance m (ft)	Detonation*	Grenades Spilled	Grenades Armed	Grenades Detonation
C10	L	0	NO	0	0	0
	R	0	NO	0	0	0
C11	L	0	NO	0	0	0
	R	0	NO	0	0	0
C12	L	0	NO	0	0	0
	R	0	NO	0	0	0
C13	L	0	NO	0	0	0
	R	0	NO	0	0	0
C14	L	0	NO	0	0	0
	R	0	NO	24	0	0
C15	L	0	NO	0	0	0
	R	0	NO	0	0	0
C16	L	0	NO	0	0	0
	R	0	NO	1	0	0
C17	L	0	NO	0	0	0
	R	0	NO	0	0	0
C18	L	0	NO	0	0	0
	R	0	NO	0	0	0

*Estimated on Tests Nos. 1 through 8 inclusive since inert acceptors were used.

Table 3. 155mm M483 HE projectiles within prototype pallet
Test Results (Phase 3)
(concluded)

Test No.	Acceptor	Separation distance m (ft)	Detonation*	Grenades Spilled	Grenades Armed	Grenades Detonation
C19	L	0	NO	8	0	0
	R	0	NO	0	0	0
C20	L	0	NO	0	0	0
	R	0	NO	0	0	0
C21	L	0	NO	0	0	0
	R	0	NO	0	0	0
C22	L	0	NO	0	0	0
	R	0	NO	0	0	0
C23	L	0	NO	0	0	0
	R	0	NO	0	0	0
C24	L	0	NO	0	0	0
	R	0	NO	0	0	0

*Estimated on Tests Nos. 1 through 8 inclusive since inert acceptors were used.

Table 4. Statistically calculated non-propagation distances (based on Phase 1 configuration data)

Propagation Probability (%)	Mean distance: At 50 percent confidence level m	(ft)	Mean distance: At 95 percent confidence level m	(ft)
5	3.1	(10.1)	6.4	(20.7)
2	6.0	(19.4)	16.7	(53.5)
1	9.2	(29.3)	29.4	(93.8)

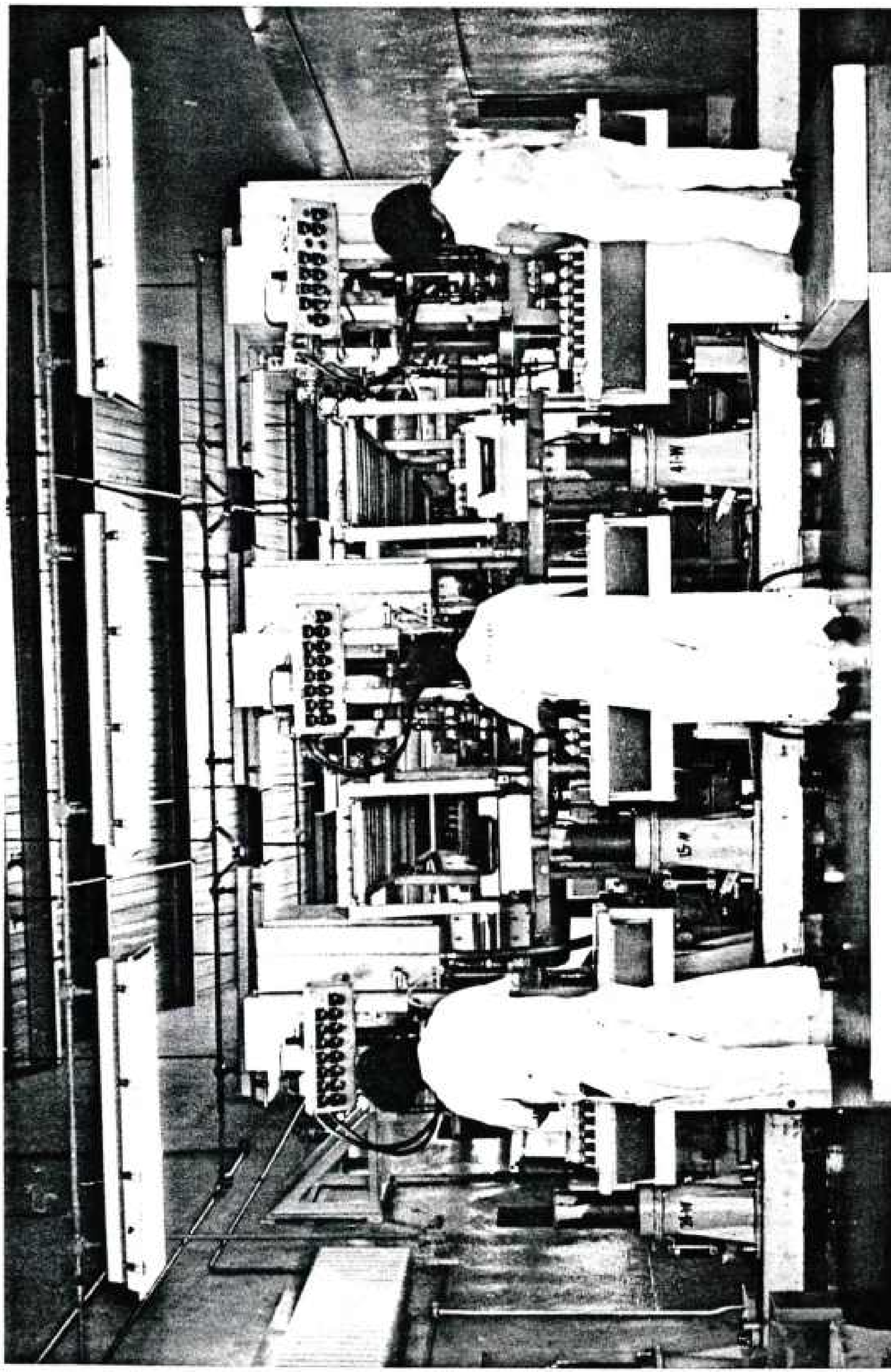

Figure 1. 155m M483 HE projectile, production line bay.

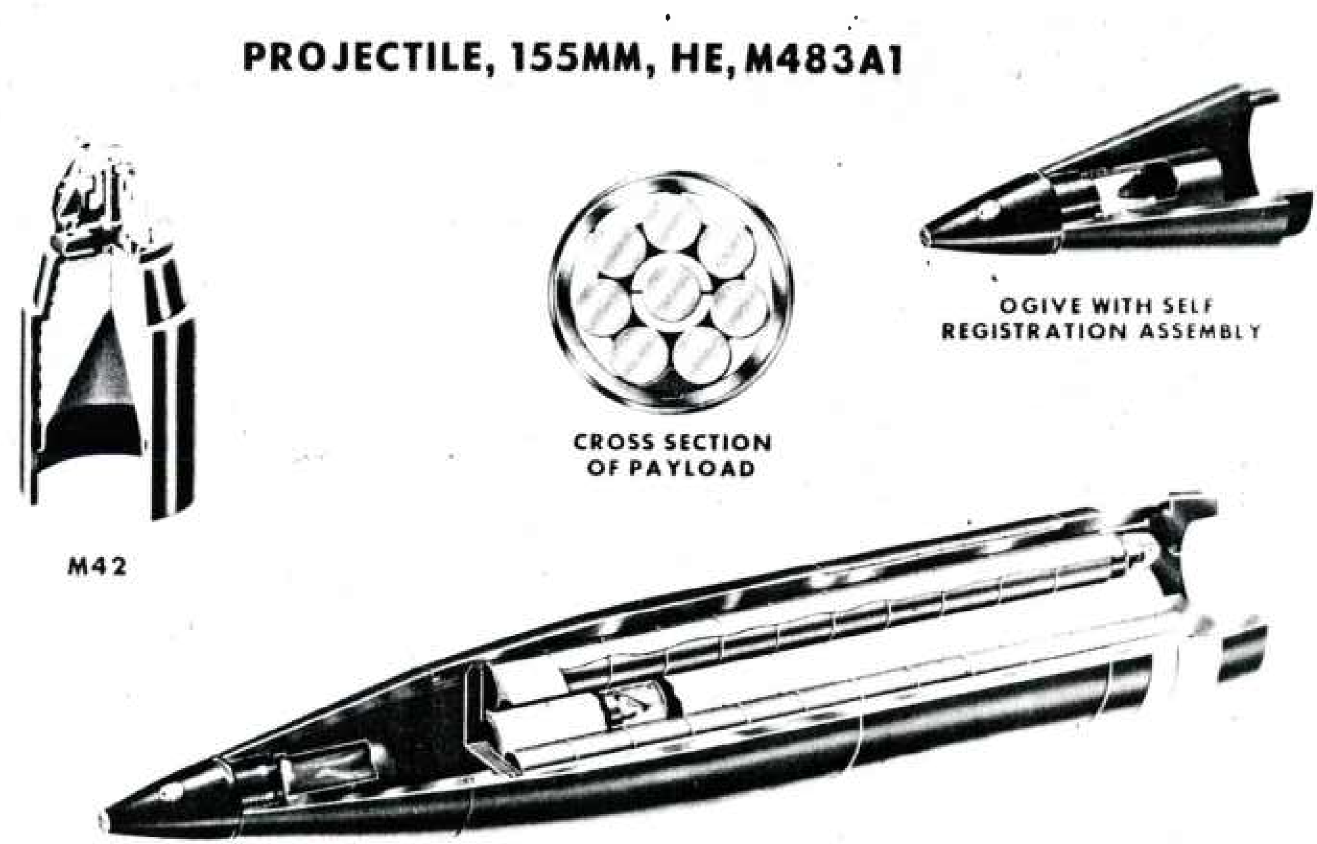

Figure 2. 155mm M483 HE projectile, cross-sectional view.

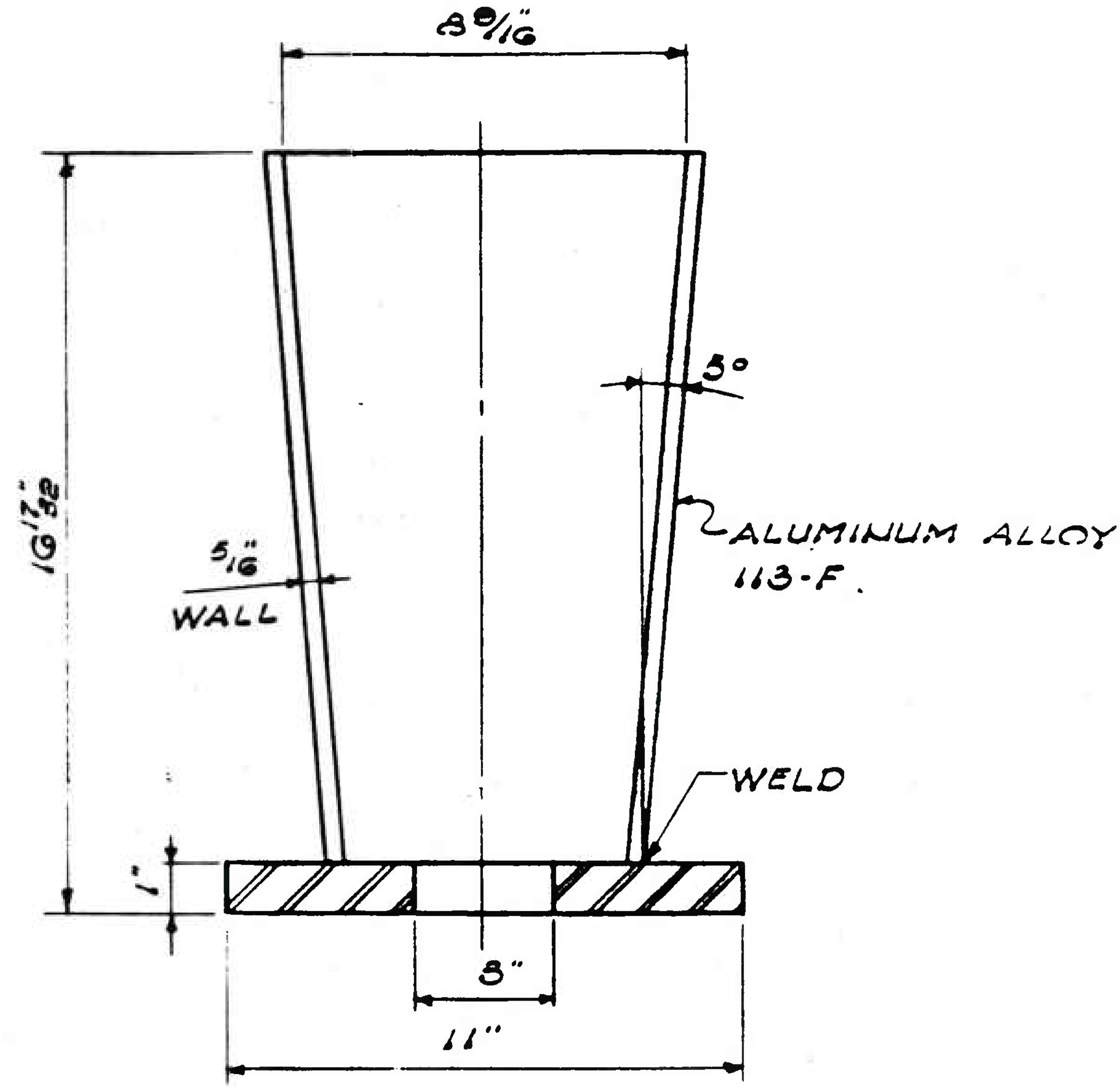

Figure 3. Simulated transfer pallet sketch.

Figure 4. Simulated pallet with test projectiles.

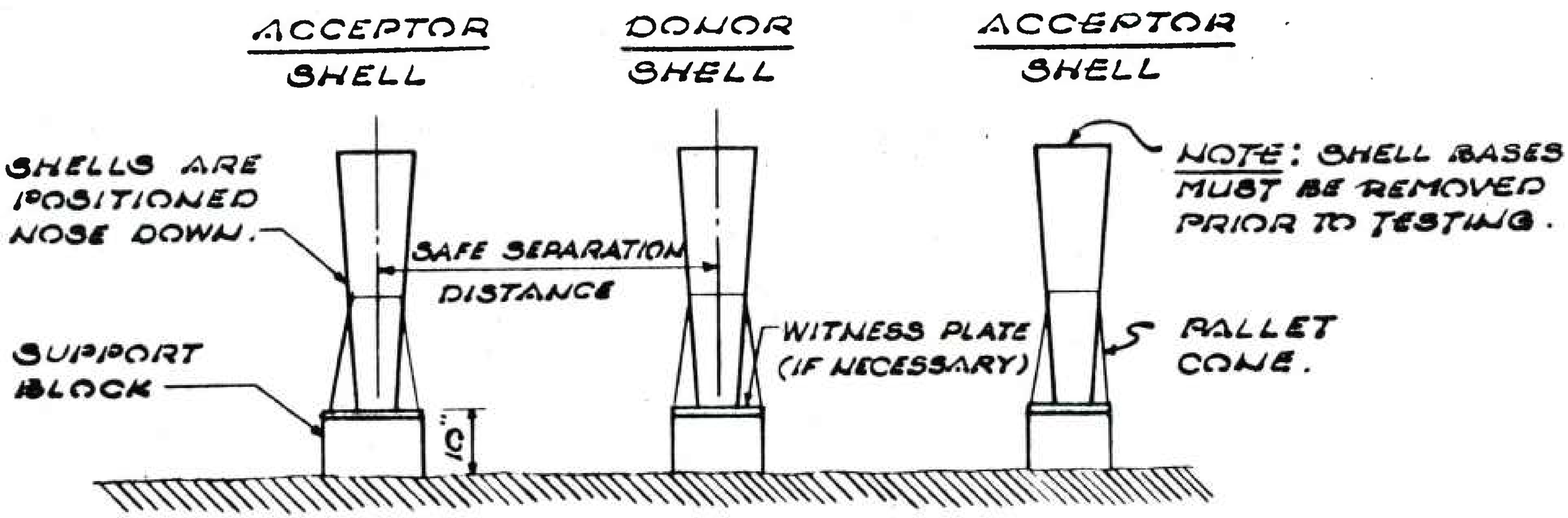

Figure 5. Phase 1, test configuration.

Figure 6. Phase 2, test array.

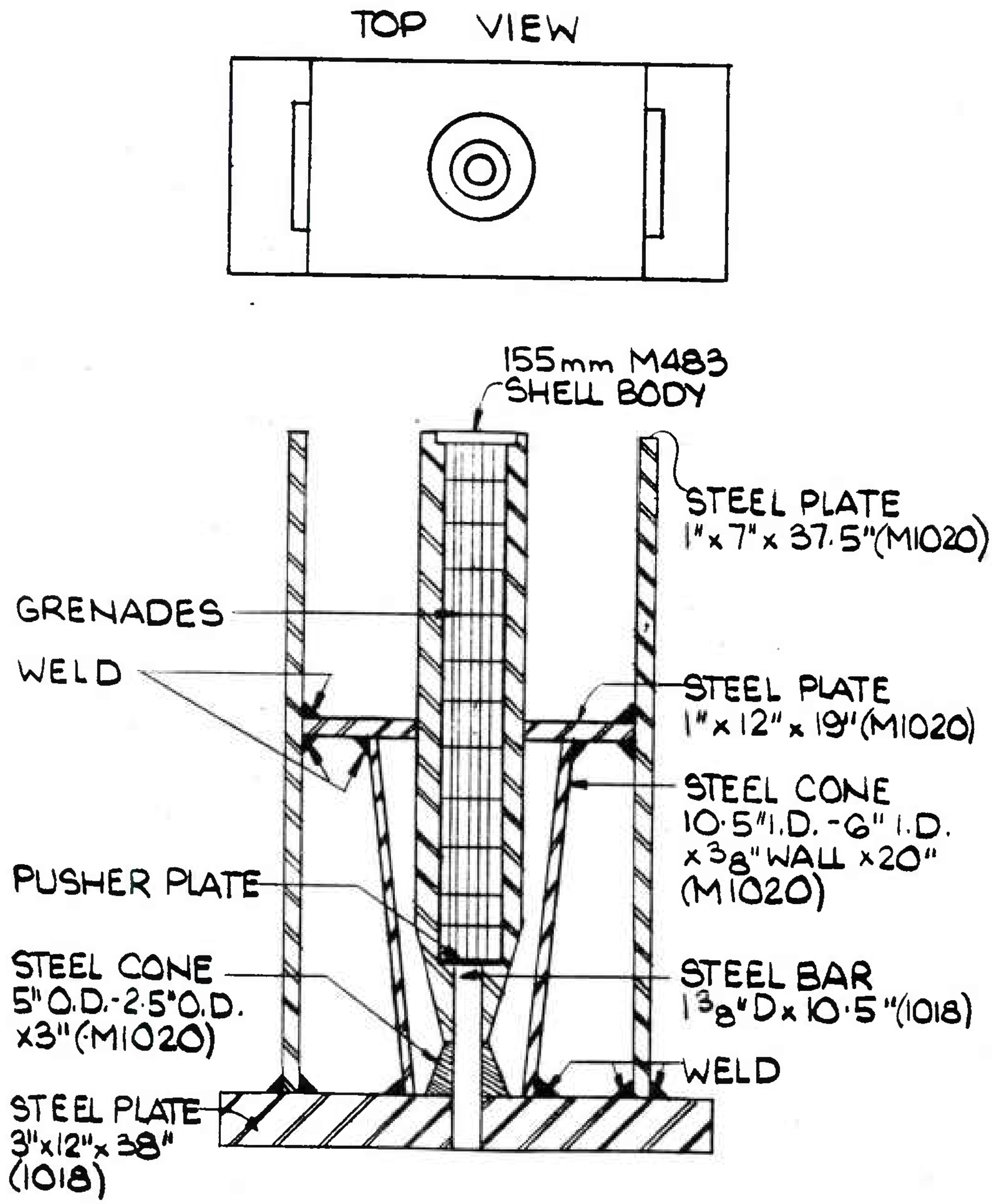

Figure 7. Prototype pallet design.

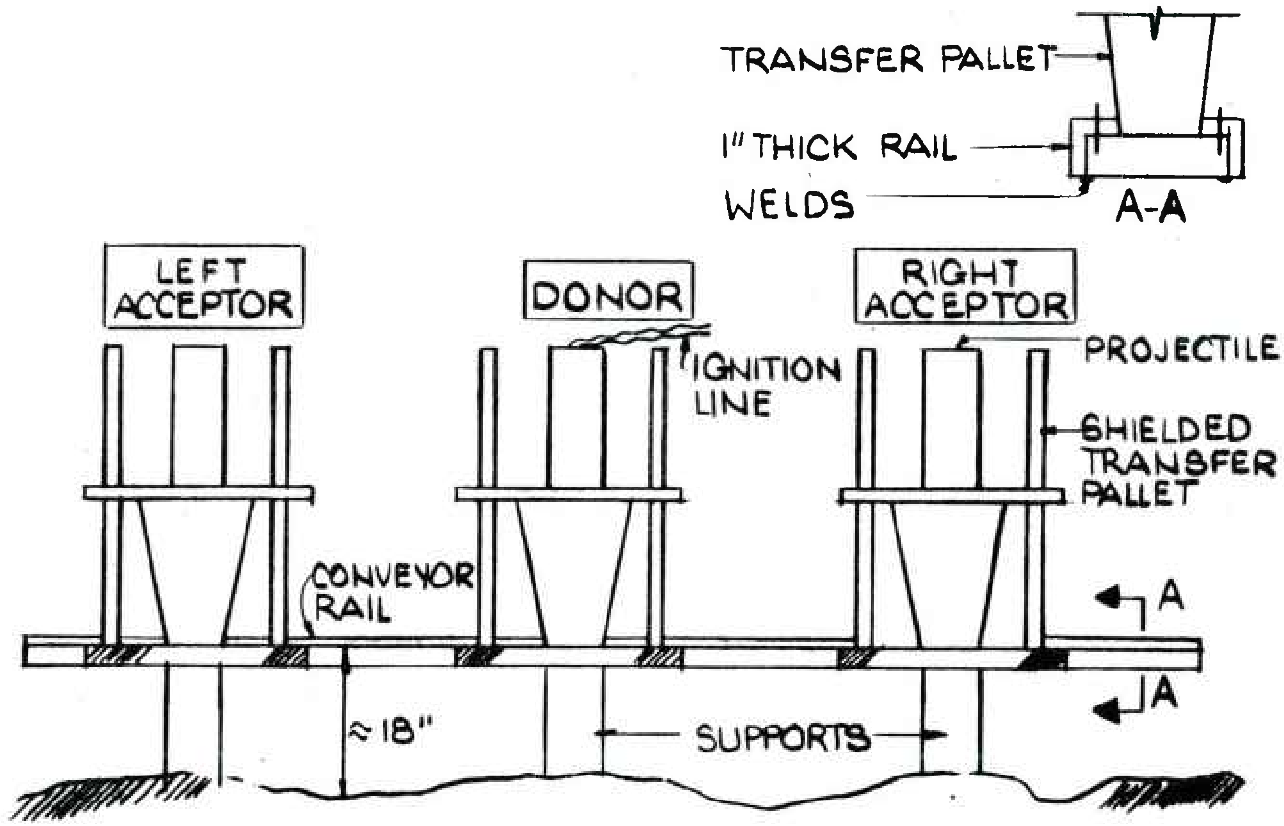

Figure 8. Phase 3, test configuration.

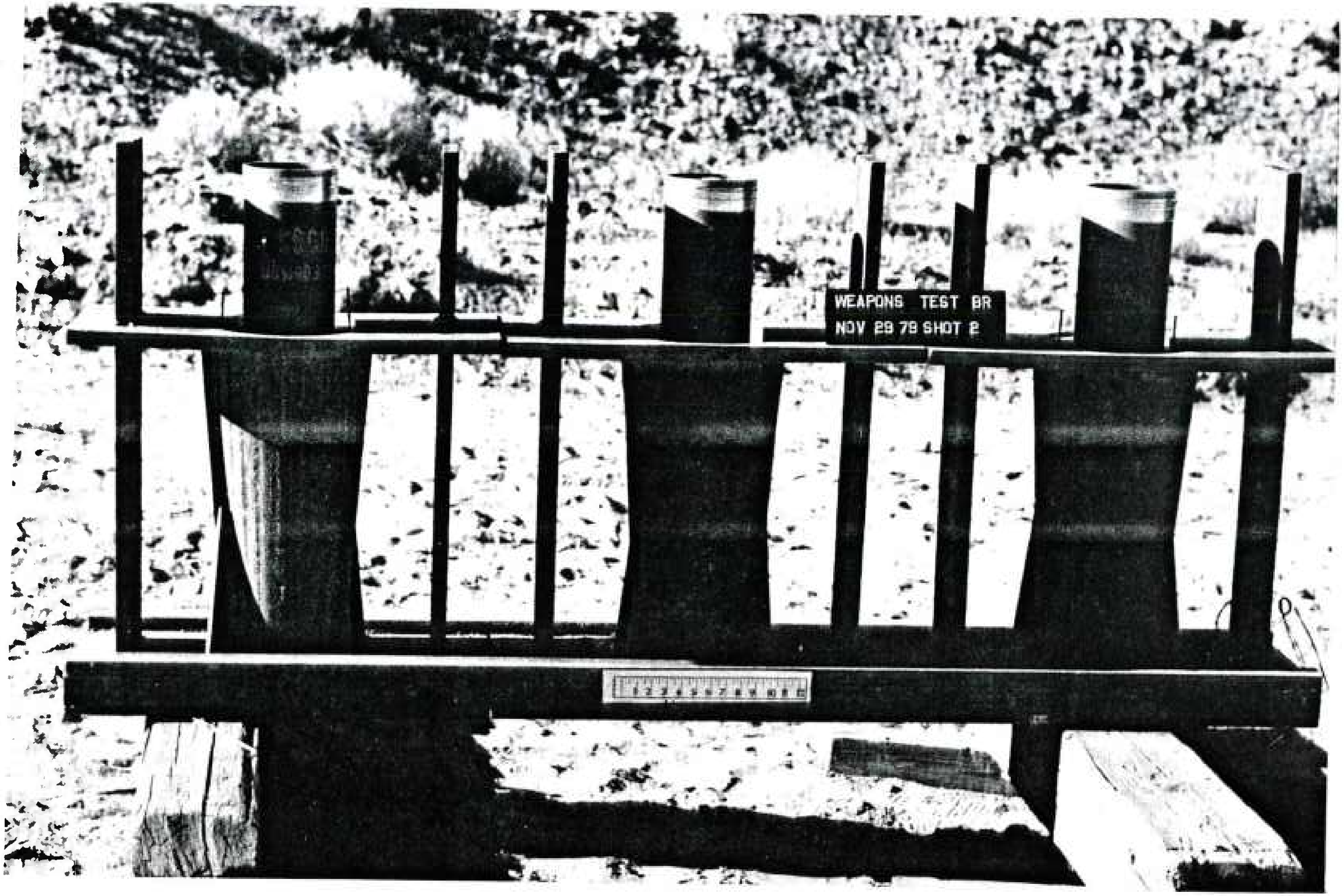

Figure 9. Phase 3, test array.

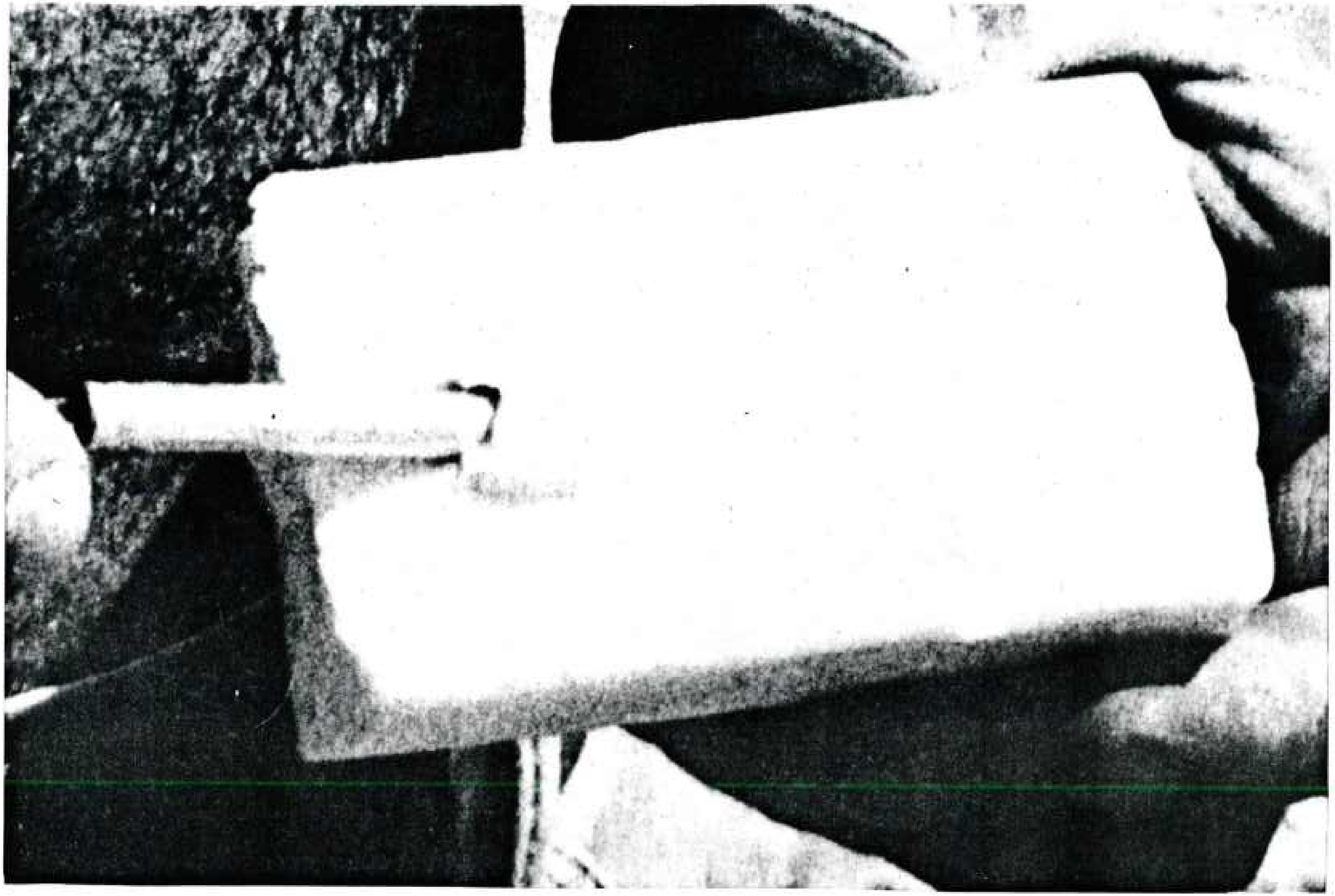

Figure 10. Test initiator, C4 explosive and blasting cap.

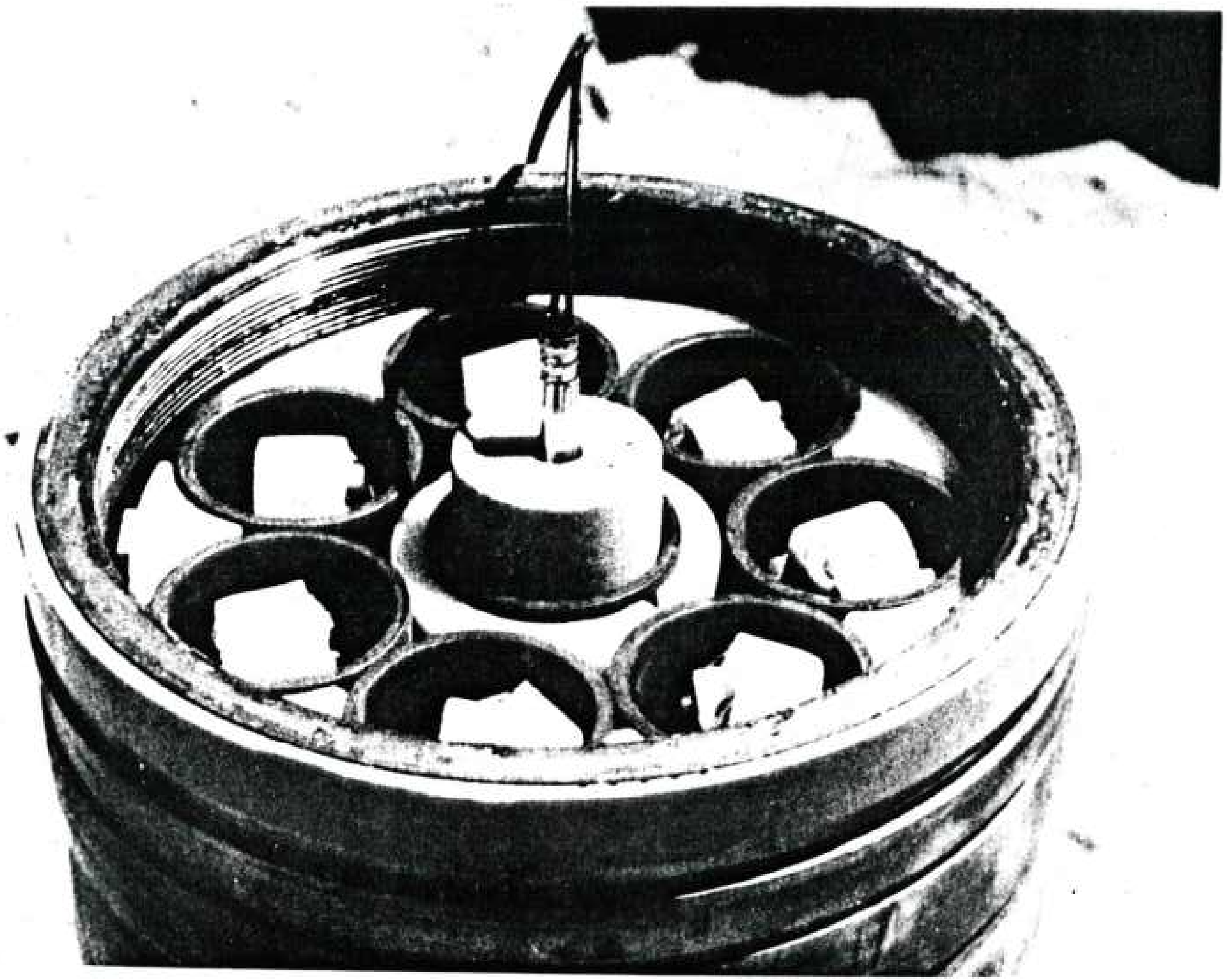

Figure 11. Test initiator, aligned blasting cap.

Figure 12. Witness plates.

Figure 13. Phase 1, post test, general view.

Figure 14. Phase 1, post test, grenade spill.

Figure 15. Phase 1, post test, ruptured pallet.

Figure 16. Phase 2, post test, shield projectile.

Figure 17. Phase 2, post test, crimped grenades.

Figure 18. Phase 3, post test, general view.

Figure 19. Phase 3, post test, recovered grenades.

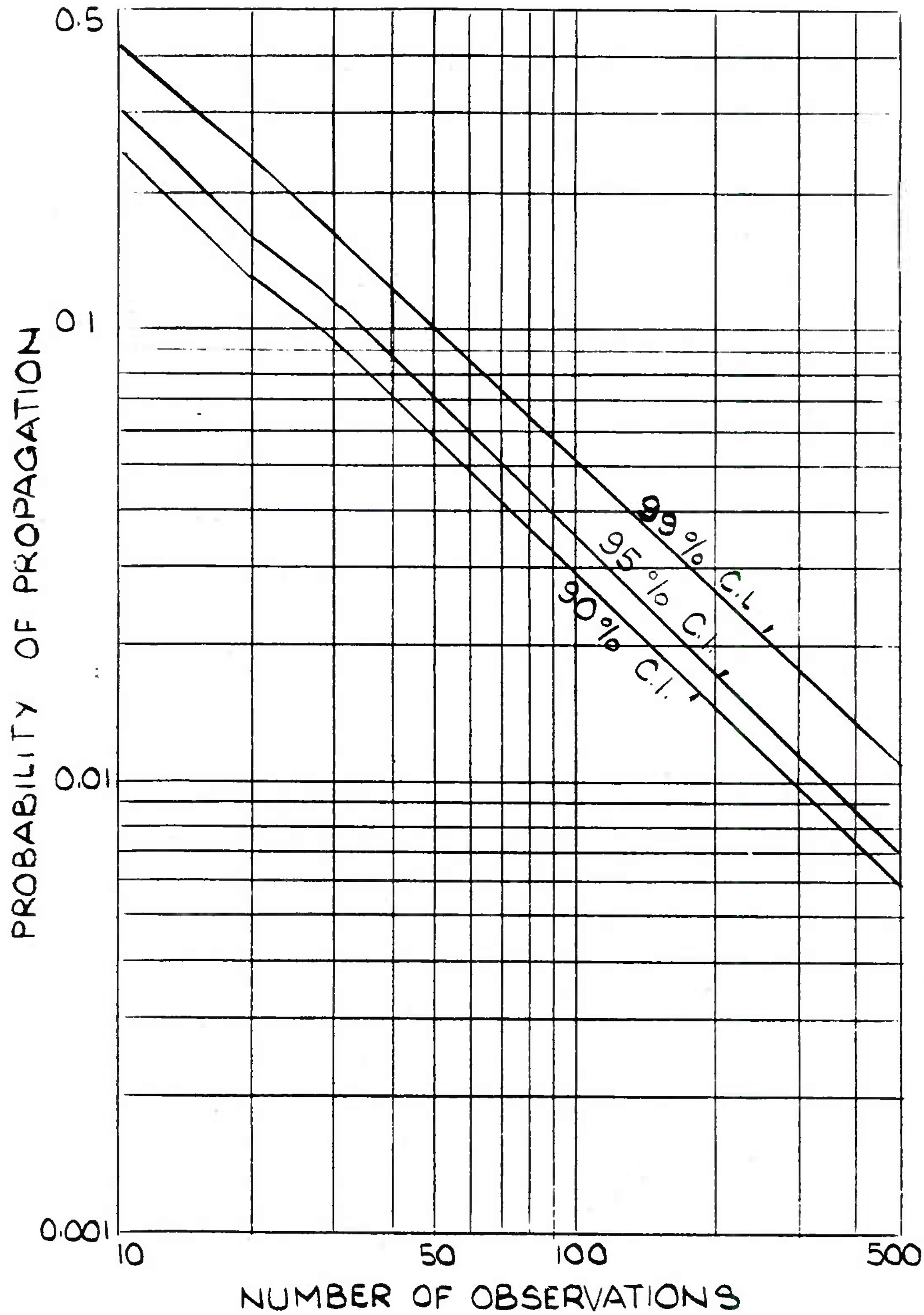

Figure 20. Variations of propagation probability vs. number of observations as a function of confidence level.

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

APPENDIX. STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

Statistical Theory

The possibility of the occurrence of explosion propagation based upon a statistical analysis of the test results has been evaluated in the main body of the report. This appendix is devoted to the mathematical means by which the statistical analysis was performed.

The probability of the occurrence of an explosion propagation is dependent upon the degree of certainty or confidence level involved and has upper and lower limits. The lower limit for all confidence levels is zero; whereas the upper limit is a function of the number of observations or, in this particular case, the number of acceptor items tested. Since each observation is independent of the others and each observation has a constant probability of a reaction occurrence (explosion propagation), the number of reactions (x) in a given number of observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by

$$p = x/n \tag{1}$$

and, therefore, the expected value of (x) is given by

$$E(x) = np \tag{2}$$

Each confidence level will have a specific upper limit (p_2) depending upon the number of observations involved. The upper probability limit for a given confidence level α, when a reaction is not observed, is expressed as

$$(1 - p_2)^n = \varepsilon \tag{3}$$

where

$$\varepsilon = (1 - \alpha)/2 \text{ and } \alpha < 1.0 \tag{4}$$

Use of equation 3 is illustrated in the following example:

<u>Example</u>

Determine the upper probability limit of the occurrence of an explosion propagation for a confidence level of 95% based upon 30 observations without a reaction occurrence.

Given

Number of Observations (n) = 30
Confidence Level (α) = 95%

Solution

1. Substitute the given value of (α) into equation 4 and solve for ε:

   $$\varepsilon = (1 - \alpha)/2 = (1 - 0.95)/2 = 0.025$$

2. Substitute the given value of (n) and value of (ε) into equation 3 and solve for p_2:

   $$\varepsilon = 0.025 = (1 - p_2)^{30}$$

   or

   $$p_2 = 0.116(11.6\%)$$

Conclusions

For a 95% confidence level and 30 observations, the true value of the probability of explosion propagation will fall between zero and 0.116; or statistically, it can be interpreted that in 30 observations, a maximum of (0.116 x 30) = 3.48 observations could result in a reaction for a 95% confidence level.

Probability Table

Table A-1 shows the probability limits and the range of the expected value E(x) for different numbers of observations. Three confidence limits, 90, 95 and 99%, are used to derive the probabilities. The same values are plotted in Figure 20.

Table A-1. Probabilities of propagation for various confidence limits

Number of observations	90%	C.L.	95%	C.L.	99%	C.L.
n	p_2	$E(x)$	p_2	$E(x)$	p_2	$E(x)$
10	0.259	2.59	0.308	3.08	0.411	4.11
20	0.131	2.62	0.168	3.36	0.233	4.66
30	0.095	2.85	0.116	3.48	0.162	4.86
40	0.072	2.88	0.088	3.52	0.124	4.96
50	0.058	2.9	0.071	3.55	0.101	5.05
60	0.049	2.92	0.060	3.6	0.085	5.10
80	0.037	2.96	0.045	3.6	0.064	5.12
100	0.030	3.0	0.036	3.6	0.052	5.2
200	0.015	3.0	0.018	3.6	0.026	5.2
300	0.010	3.0	0.012	3.6	0.018	5.4
500	0.006	3.0	0.007	3.5	0.011	5.5

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